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THE EVOLUTION AND BREAKDOWN TO TURBULENCE OF A WAVE PACKET PROPAGATING IN A LAMINAR BOUNDARY LAYER

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The research being carried out on boundary layers excitated by localised point disturbances is intended to provide fresh insight into the complex non-linear processes that occur prior to breakdown. Initially only pulsed disturbances were being considered, but recently more general forms of excitation have also been treated - pure tones, white noise and a superposition of tones and noise. "Natural" transition is initiated by the background turbulence and acoustic fields present in the flow. Unstable Tollmien-Schlichting waves are generated, and these eventually amplify sufficiently to produce a variety of non-linear interactions. The dominant non-linear features that arise are dependent on the spectrum of the wavetrain, and hence on that of the excitation provided by the environment. Observations for a range of controlled disturbances of different spectral content provide a number of different phenomena, although it is thought that these apparently diverse behaviour patterns are in some sense linked together. The non-linear evolution of a wavetrain can be considered to be defined in terms of a complex non-linear transfer function linking the input excitation to the velocity observed at some downstream location. It is therefore expected that information collected for different excitations can eventually be interpreted in terms of a single evolution equation. In parallel with the experimental work it is also essential to investigate theoretical aspects of the problem. Although quite general formulations are probably needed to satisfy the above requirements, present efforts are directed to the somewhat limited goal of obtaining a model of the evolution equation describing a three-dimensional wave

Experimental work

(i) The first part of the programme is concerned with the pulsed excitation that generates isolated wave packets. Previously a set of data had been acquired at only one excitation level, namely one large enough to generate wave packets that contained well-defined flow patterns. The observed warping of the wave crests have already positively been shown to be a non-linear effect, albeit at a surprisingly low amplitude level. A substantial amount of data concerning details of the non-linear distortions and breakdown phases of this process has already been acquired. This material involves a deal of processing for grahical display and this phase is, as yet, incomplete. The present efforts on wave packets involve recording the changes in the evolution pattern with excitation amplitude. Control of both the amplitude and the duration of the electrical pulse feeding the driving earphone is provided by a micro-computer via a D/A converter. The analogue hot-wire signal is then sampled and the ensembled averaged record stored on floppy disc. It is intended to process this data on the NMI PDP 11/44, and the necessary programs for transferring the data via magnetic tape, and for analysis and graphical display are being written.

(ii) More recently the wedged-shaped wavetrains generated by an oscillating point source has been re-examined. It is has been found that at large amplitudes the smooth and regular character of the wavetrain is gradually lost as the wave propagates far downstream. The hot-wire signals become unsteady and appear to contain random modulations of both amplitude and phase. Power spectral analysis of these records contain a significant broad-band component as well as the spectral lines associated with the fundamental and its harmonics. Analysis of a number of spectra obtained at different distances from the source, at different excitation levels and frequencies, have indicated that the broad-band element arises from freestream background turbulence that is amplified in the presence of the pure excitation tone. This is not a particularly new phenomena as far as the behaviour of non-linear differential equations is concerned but so far this effect does not seem to have been

excitation by the superposition of a pure tone and controlled psuedo-noise give an even clearer demonstration of this behaviour. This aspect of experimental work is being prepared for publication.

Theoretical

(i) Progress towards a theoretical model of a wave packet is being made. It is intended to develop a non-linear model of a three-dimensional packet evolving in a growing boundary layer. So far only the linear problem has been treated. The two-dimensional example (publication 2) can readily be extended to the three-dimensional situation. An iterative approach to the weakly non-linear equation is being attempted, but it will take some time before it is clear whether this method will yield a solution.

(ii) In view of the renewed interest in the flows generated by an oscillating point source, (work is in progress at IIT, (Chicago), and in the USSR) linear solutions of this problem are being attempted. Some calculations for the parallel flow approximation have already been carried out.

Publications

(i) Estimates of the Errors Incurred in Various Asymptotic Representations of Wave-Packets.
M. Gaster - Accepted for Publication in J. Fluid Mechanics.

(ii) The Evolution of Two-dimensional Wave Packets in a Growing Boundary Layer.
M. Gaster - Accepted for Publication in Proc. Roy. Soc. A.

Meetings

The principal investigator (M Gaster) spent some six weeks (May-June) at the University of Tel Aviv working with Professor Wygnanski and his group. This was made possible by additional support for travel and subsistence provided by the US Airforce through the University of Tel Aviv. During this visit instability theory for weakly non-parallel flow was applied to the prediction of the large scale structures that develop in a periodically forced turbulent mixing layer. A joint paper (with E Kit and I Wygnanski) comparing these predictions with measurements is being prepared for submission to the Journal of Fluid Mechanics.

Dr Gaster attended the XV Symposium on Advanced Problems and Methods in Fluid Mechanics in Poland, September 6-12.

A visit was also made to the United States, 1st November to 23 November, to the following purpose:

(i) Washington (DC) visited:
(a) AFOSR - Capt. M Francis for discussion of research on transition and turbulent spots.
(b) ONR - Dr R Whitehead to talk about a possible future joint proposal with AUWE on compliant coatings in water.

(ii) Coer D'Alene (Idaho)
To visit Dr Randles (AUWE), and to observe commissioning trials of a new vehicle undergoing "pop-ups".

(iii) Seattle (Washington) visited:
(a) "Flow Industries" to discuss their research on turbulent spots, computations of wave packets and recent efforts on compliant coatings.
(b) University of Washington to discuss work on the initial value problem with Professors W O Criminale and J Kevorkin.

(iv) Los Angeles - made visits to:

(a) University of Southern California to have discussions with Professors Laufer, Kaplan, Broward, Blackwelder, Redecop and Ho on current work on instabilities and large scale coherent structures.

(b) California Institute of Technology to see the work on heated bodies in water. (The thermal effects on the boundary layer increase the critical Reynolds number.) (Professors H W Liepmann and D Coles).

(c) Jet Propulsion Laboratory to talk to Dr L Mack about stability problems. He is using the author's series method for computing eigenvalues for the boundary layer problem of a wedge disturbance following the technique of paper (ii).

(v) Tucson (Arizona)

Visited University of Arizona to have discussions with Professor Wygnanski on the large scale structures in mixing layers in order to prepare a paper for the A.P.S meeting in Monterey. A seminar was also presented.

(vi) Palo Alto (California)

Attended a meeting at Stanford University on coherent structures in axi-symmetric jets. The meeting was supported by AFOSR and organised by Professor Nagib (Illinois Institute of Technology).

(vii) Monterey (California)

Attended the American Physical Society meeting.

Joint author of two papers:

(a) "The Feedback Mechanism of a Free Jet Measured by Laser Doppler Anemometry".

S. Einav, J. Avidor, E. Gutmark and M. Gaster.

(b) "On the Spectral Growth of Disturbances in a Slowly Diverging Turbulent Mixing Layer".

M. Gaster, E. Kit and I. Wygnanski.